1906

Metallurgical Calculations: Chimney Draft and Forced Draft

Joseph William Richards

Metallurgical Calculations.

By J. W. Richards, Ph. D.
Professor of Metallurgy in Lehigh University.

CHIMNEY DRAFT AND FORCED DRAFT.

In all problems concerning combustion, we must furnish the air needed for combustion either by suction or by pressure. The original and almost universal method is by chimney draft; the more positive and reliable method is forced draft. Often the two are combined with very satisfactory results.

The waste heat from any metallurgical process or furnace is generally considerable. Most furnaces must be kept above a red heat, and the gases pass directly out of the furnace into the chimney. In such cases the chimney is indicated as the proper source of draft, because it utilizes, although very inefficiently, the ascensive force of the hot gases, and thus works by otherwise wasted energy. In other cases it is practicable to pass the gases through boilers before they go to the chimney, and thus to raise large amounts of steam. The gases are then cooled down so far that they enter the chimney too cold to furnish all the draft needed; in such cases a small fraction of the steam generated will run a steam engine or steam turbine, and run a fan capable of furnishing all the draft needed. In this manner considerable steam is available for other purposes, and great economy is effected.

Chimney Draft.

The principles involved are not obscure or complicated. The total pull, or suction, which a chimney can produce, assuming it to be filled with hot air, is simply due to the ascensive force of the hot air inside, and the measure of this is the difference of weight of the chimney full of hot gases and what it would be if filled with cold air of the temperature outside.

Illustration: A chimney is 6 feet square inside and 100 feet high, uniform, with the gases inside at an average temperature of 500° F., and specific gravity (air = 1) of 1.06. The air outside is at 80° F. What is the ascensive force of the hot gas inside, in total pounds, in ounces per square inch and inches of water gauge?

The volume of the space in the chimney—chimney volume—is $100 \times 6 \times 6 = 3600$ cubic feet. This volume, filled with air at 32° F., would weigh

$$3600 \times 1.293 = 4654.8 \text{ oz. Av.} = 290.9 \text{ pounds.}$$

And, filled with gas at 500° F.,

$$290.9 \times 1.06 \times \frac{491}{500 - 32 + 491} = 157.9 \text{ pounds.}$$

If filled with outside air, at 80° F., the weight would be

$$290.9 \times \frac{491}{80 - 32 + 491} = 265.0 \text{ pounds.}$$

We, therefore, see that the hot gases in the chimney, weighing 157.9 pounds, displace 265.0 pounds of cold air, and the tendency of the former to rise upwards in this ocean of air must be

$$265.0 - 157.9 = 107.1 \text{ pounds.}$$

To put it in another way, if a piston fitted into the chimney at the bottom, and could move without friction, the piston would have to be loaded with 107.1 pounds to keep it from moving up the chimney. The total upward pull of the chimney is therefore 107.1 pounds.

Since this would be exerted on a piston $6 \times 6 = 36$ square feet in area, the pull or suction per square foot, in pounds, is $107.1 \div 36 = 2.98$ pounds, and in ounces per square inch

$$(2.98 \div 144) \times 16 = 0.331 \text{ ounce per square inch.}$$

If the pull or suction is measured on a gauge, as by water pressure, the pressure of a 1-foot column of water at ordinary temperatures is 1000 ounces per square foot, or 1 inch of water is

$$(1000 \div 144) \div 12 = 0.597 \text{ ounces per square inch.}$$

The total pull of the chimney is therefore equivalent to

$$\frac{0.331}{0.579} = 0.57 \text{ inch of water gauge.}$$

By exactly similar methods of calculation the theoretical total suction of a chimney of any given height and temperature of gases inside and of air outside may be obtained. The suction expressed in ounces per square inch, or in water gauge is, of course, independent of the cross-sectional area of the chimney; it depends only on its height and on the temperatures inside and outside.

The above calculated total suction (allowing nothing for friction, etc.) is called the total head of the chimney, and is usually expressed in terms of cold air (at 0° C.) instead of in water. Cold air is a fluid, and water is 772 times as heavy as it; therefore, a gauge pressure or hydrostatic head of 0.57 inch of water is the same as

$$0.57 \times 772 = 440 \text{ inches of air.}$$
$$= 36.5 \text{ feet of air.}$$

What this head really represents is clearly seen from the above calculations. Its value is to be obtained directly from the height of the chimney, temperature inside and out and specific gravity of the chimney gases (air = 1) by the following relations, in which

h_0 = total head in feet of air at 32° F.
h_0 = total head in meters of air at 0° C.
t = temperature in the chimney, F°.
t = temperature in the chimney, C°.
t' = temperature of outside air, F°.
t' = temperature of outside air, C°.
D = Specific gravity of chimney gases, air = 1.
H = Height of chimney in feet.
H = Height of chimney in meters.

coef = coefficient of gaseous expansion, F° $= \frac{1}{491}$

coef = Coefficient of gaseous expansion, C° $\frac{1}{273} = a$

$$h_0 = H\left[\frac{(1-D) + coef\,[(t-32) - D\,(t'-32)]}{[1 + coef\,(t'-32)]\,[1 + coef\,(t-32)]}\right]$$

$$\mathrm{h}_0 = \mathrm{H}\left[\frac{(1 - D + \mathrm{coef}\,(t - D\,t')}{(1 + \alpha t')\,(1 + \alpha t)}\right]$$

The author is not fond of using formulas whenever their use can be avoided. The above formulas express in the simplest mathematical form the principles which have been so far explained and used in the calculations, but it is strongly urged that the formulas be kept "for exhibition purposes only," and that when any specific case is to be worked it be attacked from the standpoint of the principles involved, as explained in the case worked. In other words, if one understands properly and thoroughly the basic principles, he has no need of the formula; if one does not understand the principles, the formula had better be kept forever in "innocuous desuetude."

The total head, obtained as above, is the theoretical head. It is like the pressure on the piston of a locomotive—the total available force for all purposes. Just as the pressure on the locomotive piston is used up in friction in the engine and in moving the engine itself, and the residue is the *available* pull on the draw-bar which moves the train, so the total head of the chimney is partly used up in friction in the chimney itself, partly in giving velocity to the gases as they pass out of the chimney, and the residue is the *available* head which draws or pulls the gases through fire-grates, furnaces and flues up to the base of the chimney. If the chimney could be momentarily completely closed at the bottom, except for the gauge opening, and the air inside be brought to rest, the gauge would show the total head; as soon as dampers are opened connecting the flues, air moves up the chimney, and the gauge pressure is lessened by the head required to move the gases and that absorbed in their friction in the chimney.

Head Represented in Velocity of Issuing Gases.—This item always exists when the chimney is working, and depends only on the velocity of the gases as they escape and their temperature. The hydraulic head necessary to give any fluid a velocity V is simply the same as the height which a falling body must fall in order to acquire that same velocity; *i. e.:*

$$h = \frac{V^2}{2g}$$

in which expression, 2g is the constant acceleration of gravity, 19.6 meters or 64.3 feet, and the velocity is in meters or feet per second. If we know, therefore, the velocity of the gases issuing from the chimney, or can calculate or assume it, we can get h. In practice the velocity does not vary within very wide limits. In small house chimneys it may not exceed 3 feet per second, in boiler chimneys 6 to 12 feet per second, in furnace chimneys 12 to 20 feet per second. The temperatures of these issuing gases is, moreover

	C°	F°
In small chimneys......	100 to 200	200 — 350
In boiler chimneys......	100 to 300	200° — 550
In furnace chimneys....	300 to 1000	550° — 1800°

If the chimney in question has, therefore, a known velocity of exit of its gases, h can be calculated; but it must not be forgotten that h will be in terms of the kind of gases which is escaping; *i. e.*, of hot gas, and to subtract it from or compare it with h_0 we must reduce it to its equivalent head in terms of cold gas. This is merely a matter of taking into account the specific gravities or relative densities of hot gas and cold air, which are inversely proportional to their absolute temperatures; that is, if D represents the relative density of air and chimney gases at the same temperature:

$$\mathrm{h}_0\,\mathrm{vel.} = \mathrm{h} \times \frac{D}{1 + \alpha t} = \frac{V^2}{2g} \cdot \frac{D}{1 + \alpha t}$$

Illustration: Assuming the actual velocity of the gases issuing from a furnace chimney to be 15 feet per second, and their temperature 500° F., density 1.06 (air = 1), what will be the head represented by the velocity of these gases in terms of cold air at 32° F?

The head represented, *in terms of hot gases at* 500° *F.*, is

$$h = \frac{V^2}{2g} = \frac{15^2}{64.3} = 3.5 \text{ feet.}$$

In terms of air at 500° F. is

$$3.5 \times 1.06 = 3.71 \text{ feet.}$$

And in terms of air at 32° F.,

$$3.71 \times \frac{491}{500 - 32 + 491} = 1.9 \text{ feet.}$$

Out of the total head which this chimney produces (say 36.5 feet) 1.9 feet is represented by the velocity of the issuing gases, or 5.2 per cent of the whole, leaving 34.6 feet to represent loss by friction in the chimney and the available head. We will proceed to discuss the loss of head due to friction in the chimney.

Head Lost in Friction in the Chimney.—This varies with the smoothness or roughness of the walls, and has been determined experimentally for air moving with different velocities. The manner of expressing the friction loss is, to put it as a function of the head necessary to give the gases their actual velocity, assuming there were no friction. Thus, supposing as in the preceding paragraph, the actual velocity of the hot gases is 15 feet per second, and the head (in terms of cold air) necessary to give that velocity, not considering friction, is 1.9 feet, then the head lost in friction in getting up this velocity will be

$$h_{\text{friction}} = 1.9 \times \frac{H}{d} K.$$

That is, it will be proportional to H, the height of the chimney, inversely as d, the diameter or side, if square, and to a coefficient K, determined by experiment. The latter varies, according to Grashof's experiments, between 0.05 for a smooth interior to 0.12 for a rough one, and averages 0.08.

Illustrations: Assuming the height of the chimney 100 feet, its section to be 6 feet square, the coefficient of friction K = 0.08, and the head represented by the net velocity of the hot gases in the chimney to be 1.9 feet of cold air, what is the head lost in friction in the chimney?

The ratio of height to side is $100 \div 6 = 16.67$, which multiplied by K gives 1.33 as the value of the function containing these three terms. This means that 1.33 times as much head has been lost in friction as is represented by the net actual velocity of the gases as they pass up the chimney. Therefore,

$$h_{\text{friction}} = 1.9 \times 1.33 = 2.5 \text{ feet cold air.}$$

Another way of looking at this, which is sometimes useful in considering the height of a chimney, is to say

$$h_{\text{friction}} = 0.025\ H.$$

Or, that in this case, the head lost in friction amounts numerically to one-fortieth the height of the chimney.

If we subtract the head lost in friction plus that represented in the net velocity of the gases, from the total gross head, the residue is that available for doing work external to the chimney. In the specific case of the preceding illustrations we have

h_0 = total head	= 36.5 feet	=	100 per cent	
h_{velocity} = velocity head	= 1.9 "	=	5	"
h_{friction} = friction in chimney	= 2.5 "	=	7	"
$h_{\text{available}}$ = available head	= 32.1 "	=	88	"

Available Head of a Chimney.—This is the part of the total head which remains after subtracting the head lost in friction in the chimney and that represented by the velocity of the issuing gases. In the specific cases considered in the above illustrations, the net available head amounted to 88 per cent of the whole theoreticial head. If we assume limiting conditions as found in practice, we can find the limiting values of this proportion. Calling the cases I and II, those with minimum and maximum absorption of head in the chimney itself, we have

	Case I.	*Case II.*
Temperature of issuing gases	100° C.	1000° C.
Velocity of issuing gases per second	1 meter	7 meters
Ratio H to d	10	50
Coefficient K	0.05	0.12
Specific gravity of gases (air = 1)	1.00	1.06
Head as velocity of gases (meters of air)	0.04 m.	0.56 m.
Head as velocity of gases (feet or air)	0.13	1.87
Head absorbed in friction (meters of air)	0.02	3.36
Head absorbed in friction (feet of air)	0.07	11.2
Head used up in chimney (meters)	0.06 to	3.92
Head used up in chimney (feet)	0.20 to	13.0
Water gauge pressure thus lost, m. m.	0.1 to	5.0
Water gauge pressure thus lost, inches	0.003 to	0.2

The available head will, therefore, be the theoretical total head minus a loss in the chimney itself, which may amount to a maximum of 3.9 meters or 13 feet, representing an absorption of water gauge pressure up to 5 millimeters, or 0.2 inch at a maximum. Under ordinary conditions half these quantities would be a rather high chimney loss.

In most conditions which confront the metallurgist, the question is to determine how high a chimney should be built in order to supply a certain available draft determined by practice to be necessary. For instance, to burn a certain amount of coal per hour on any grate requires a certain amount of draft. This amount is increased if the draft is increased, and *vice versa.* In boilers, 18 pounds of coal burned per square foot of grate surface per hour is highly economical practice, and requires a draft of 0.4 inch to 0.8 inch of water gauge, according to the kind of coal burned. In furnaces where the amount of coal burned is greater per hour there will be usually a correspondingly greater temperature in the chimney. To calculate the height of chimney required it is necessary to assume only the temperature in the chimney, the available draft required and an average chimney loss.

Problem 19.

It is desired to design a chimney for a puddling furnace, the grate of which is 4 feet by 6 feet, and which shall burn 30 pounds of bituminous coal per hour per square foot of grate surface. Temperature of gases entering the chimney 1200° C., at the top probably 1000° C. Specific gravity of gases 1.03 (air = 1). Draft required 0.6 inch of water gauge. Outside temperature 30° C.

Solution: We can assume that since the gases will be at an average temperature of 1100° C. in the chimney, their velocity will be high, and that at least 0.1 inch of water gauge pressure will be absorbed by the chimney itself. This makes a total requirement of 0.7 inches of water for total head, or

$$h_0 = 0.7 \times 772 \div 12 = 45 \text{ feet of cold air.}$$

Or an unbalanced pressure or ascensive force of

$$45 \times 1.293 \div 16 = 3.64 \text{ pounds per square foot.}$$

Considering the air outside the chimney, its weight at 30° C. is equal, per cubic foot,

$$1.293 \times \frac{273}{303} \div 16 = 0.073 \text{ pounds.}$$

The gases inside the chimney weigh, per cubic foot,

$$1.293 \times 1.03 \times \frac{273}{1100 + 273} \div 16 = 0.0166 \text{ pounds.}$$

The height of the chimney being called H and its cross-section S, the volume is H × S, and the weight of hot air inside it is

$$(H \times S) \times 0.0166 \text{ pounds.}$$

And of an equal volume of cold air outside

$$(H \times S) \times 0.073 \text{ pounds,}$$

giving a total ascensive force of

$$(H \times S) \times 0.0564 \text{ pounds.}$$

But there is needed a total ascensive force of

$$S \times 3.64 \text{ pounds,}$$

in order to give the pull of 3.64 pounds per square foot, and, therefore, of necessity,

$$H \times S \times 0.0564 = S \times 3.64,$$

from which

$$H = \frac{3.64}{0.0564} = 64.5 \text{ feet.}$$

Concerning the cross-section of this chimney, it would not be safe to make it less in diameter than one-fiftieth of its height, because of lack of stability; in fact, one-twenty-fifth would be better practice. This consideration would make its internal diameter 2 ft. 7 inches, area 5.2 square feet. Another way of arriving at a diameter is to calculate the volume of the hot gases which must pass up the chimney, and assume for them some maximum velocity in the chimney, such as, let us say, 6 meters (20 feet) per second, and so get the minimum area necessary for filling this condition as follows:

Coal burnt per hour $4 \times 6 \times 30$	=	720 pounds.
Air theoretically necessary, assuming average bituminous coal (See Prob. 1) $= 123 \times 720$	=	88,560 cubic feet
Products of combustion at standard conditions $= 129 \times 720$	=	92,880 "
Volume chimney gases at 1100° C. $= 92{,}880 \times \dfrac{1700 + 273}{273}$	=	467,100 "
Volume per second	=	130 "
Area of chimney, if maximum velocity is 20 feet per second	=	6.5 square feet
Diameter, if round	=	2 ft. 10 ins.

This chimney would do its work better, and there would be much less loss in friction, if the internal diameter were made 25 per cent greater than the above calculated minimum, say, therefore, 3 feet 6 inches, making the area nearly 50 per cent greater, and cutting down the velocity in the chimney to 13.5 feet per second.

Problem 20.

In the case of the puddling furnace of Problem 19, assume that the hot gases, instead of going directly into the chimney, are passed through the flues of a boiler placed above the furnace, and thence pass into the chimney at a point 15 feet higher than before. Assume chimney 3 feet 6 inches internal diameter, 64.5 feet high above the furnace flue, and that the gases now passing into it 15 feet higher up are at 350° C., and cool to 250° C. at the top of the chimney. The boiler flues introduce additional frictional resistance equal to 0.1 inch of water. The boiler raises steam at a net efficiency of 45 per cent, the steam engine utilizes the steam at a mechanical efficiency of 20 per cent, and a centrifugal fan supplies the forced draft needed at a mechanical efficiency of 25 per cent.

Required: (1) The total head of the chimney, when the furnace discharged directly into it, and the average temperature of the gases in it was 1100° C., and specific gravity 1.03 (air = 1).

(2) The head absorbed as velocity of the outgoing gases, their temperature being 1000° C.

(3) The head lost in friction in the chimney, in this case.

(4) The head which was available to run the puddling furnace.

(5) The total head of the chimney with the gases entering 15 feet above former flue, and average temperature 300° C.

(6) The head absorbed in this case as velocity of outgoing gases, their temperature being 250° C.

(7) The head lost in friction in the chimney in this case.

(8) The available head to draw gases into the chimney.

(9) The deficit of head which must be made up by forced blast under the grate of puddling furnace.

(10) The horse-power absorbed by the fan which furnishes this blast.

(11) The horse-power furnished by the engine using the steam from the boiler.

(12) The excess of power which is thus saved and available for other purposes.

Solution:

(1) Volume of gases in chimney,

$$64.5 \times 3.5 \times 3.5 \times 0.7854 = 620.5 \text{ cu. ft.}$$

Weight at 32° F. (0° C.),

$$620.5 \times (1.293 \div 16) \times 1.03 = 51.65 \text{ lbs.}$$

Weight if temperature is 1100° C.,

$$51.65 \times \frac{273}{1100 + 273} = 10.27 \text{ lbs.}$$

Weight of equal volume of air outside at 30° C.,

$$620.5 \times (1.293 \div 16) \times \frac{273}{30 + 273} = 45.18 \text{ lbs.}$$

Difference of weight = ascensive force,

$$45.18 - 10.27 = 34.91 \text{ lbs.}$$

Ascensive force per square foot,

$$34.91 \div 9.62 = 3.63 \text{ lbs.}$$

Total head in terms of cold air at 0° C.,

$$3.63 \div (1.293 \div 16) = \mathbf{44.9} \text{ ft.} \qquad (1)$$

In terms of water gauge pressure,

$$44.9 \times 12 \div 772 = \mathbf{0.685} \text{ ins.} \qquad (1)$$

(2) Volume of gases per hour at 0° C.,

$$\text{(Prob. 19)} = 92{,}800 \text{ cu. ft.}$$

Volume at 1000° C.,

$$= 92{,}880 \times \frac{1000 + 273}{273} = 433{,}100 \text{ cu. ft.}$$

Velocity per second,

$$433{,}100 \div (3600) \div 9.62 = 12.50 \text{ ft.}$$

Head necessary to give this velocity, in terms of hot gases, at $1000° = (12.50)^2 \div 64.3\ (2g) = 2.43$ ft.

In terms of gases at 0° C.,

$$2.43 \times \frac{273}{1000 + 273} = 0.52 \text{ ft.}$$

In terms of air at 0° C.,

$$0.52 \times 1.03 = \mathbf{0.55} \text{ ft.} \qquad (2)$$

In terms of water gauge pressure,

$$0.55 \times 12 \div 772 = \mathbf{0.008} \text{ in.} \qquad (2)$$

(3) Assuming K, the coefficient of friction, 0.08, then

$$h_0 \text{ friction} = \frac{V^2}{2g} \; \frac{273}{273 + t} \; \frac{H}{d} K \cdot D.$$

This is only an abbreviated form of the operations done under (2), adding the terms which account for the height, diameter and friction. Now, the velocity per second:

$$V = 92{,}880 \times \frac{1100 + 273}{273} \div 3600 \div 9.62 = 13.5 \text{ ft.}$$

Head necessary to give this velocity in terms of air at 0°,

$$(13.5)^2 \div 64.3 \times \frac{273}{273 + 1100} \times 1.03 = 0.58 \text{ ft.}$$

Proportion of this velocity head lost in friction =

$$\frac{H}{d} K = \frac{64.5}{3.5} \times 0.08 = 1.47$$

Head lost in friction in chimney,

$$0.58 \div 1.47 = \mathbf{0.85} \text{ ft.} \qquad (3)$$

In terms of water gauge pressure,

$$0.85 \times 12 \div 772 = \mathbf{0.013} \text{ in.} \qquad (3)$$

(4)	*Cold Air.*	*Water Gauge.*	
Total head	44.90 feet	0.685 inch	
Absorbed in velocity of gases....	0.55 "	0.008 "	
Absorbed in friction in chimney..	0.85 "	0.013 "	
Available for the furnace.......	43.50 "	0.664 "	(4)

(5) Volume of chimney gases,

$$(64.5 - 15) \times 3.5 \times 3.5 \times 0.7854 = 475.7 \text{ cu. ft.}$$

Weight at 300° C., specific gravity 1.03 (air = 1),

$$475.7 \times (1.293 \div 16) \times 1.03 \times \frac{273}{273 + 300} = 18.86 \text{ lbs.}$$

Weight of equal volume of outside air at 30° C.,

$$475.7 \times (1.293 \div 16) \times \frac{273}{273 + 30} = 34.68 \text{ lbs.}$$

Ascensive force of air per square foot,

$$(34.68 - 18.86) \div 9.62 = 1.64 \text{ lbs.}$$

Total head in terms of cold air,

$$1.64 \div (1.293 \div 16) = \mathbf{20.3} \text{ ft.} \qquad (5)$$

In terms of water gauge pressure,

$$20.3 \times 12 \div 772 = \mathbf{0.32} \text{ in.} \qquad (5)$$

(6) Velocity of issuing gases, per second, at 250° C.,

$$92{,}880 \times \frac{250 + 273}{273} \div 3{,}600 \div 9.62 = 5.14 \text{ ft.}$$

Head as velocity in terms of cold air at 0° C.,

$$(5.14)^2 \div 64.3 \times \frac{273}{273 + 250} \times 1.03 = \mathbf{0.22} \text{ ft.}$$

In terms of water gauge pressure = **0.003** in.

(7) Average velocity of gases in chimney at 300° C.,

$$92{,}880 \div 3{,}600 \times \frac{300 + 273}{273} \div 9.62 = 5.63 \text{ ft.}$$

Head lost in friction in terms of cold air,

$$(5.63)^2 \div 64.3 \times \frac{273}{300 + 273} \times 1.03 \times \frac{49.5}{3.5} \times 0.08 = \mathbf{0.27} \text{ ft.} \qquad (7)$$

In terms of water gauge pressure = **0.004** in. (7)

(8)	*Cold Air.*	*Water Gauge.*	
Total head	20.30 feet	0.320 inch	
Absorbed in velocity of gases....	0.22 "	0.003 "	
Absorbed in friction in chimney..	0.27 "	0.004 "	
Available to draw gases in.....	**19.81** "	**0.313** "	(8)

(9)			
Available head needed for puddling (4)....................	43.50 "	0.664 "	
Available head needed for boiler.	6.43 "	0.100 "	
Total head needed for both......	46.93 "	0.746 "	
Available head from chimney (8)	19.81 "	0.313 "	
Deficit, to be supplied by blast...	**27.12** "	**0.451** "	(9)

(10) The 0.451 inches of water gauge equals

$$(0.451 \div 12) \times 62.5 = 2.35 \text{ lbs. per sq. ft.}$$

The volume of air to be supplied is, at 30° C.,

$$88{,}560 \text{ (Prob. 19)} \div 60 \times \frac{273 + 30}{273} = 1{,}638 \text{ cu. ft. per min.}$$

Net work done by the fan,

$$1{,}638 \times 2.35 = 3{,}850 \text{ ft. lbs. per min.}$$

Gross power needed by the fan,

$$3{,}850 \div 0.25 \text{ (efficiency)} = 15{,}400 \text{ ft. lbs. per min.}$$

Horse-power needed to drive the fan,

$$15{,}400 \div 33{,}000 = \mathbf{0.47} \text{ H. P.} \qquad (10)$$

(11) The boiler receives the gases at 1200° C., and discharges them at 350°, and 92,880 cubic feet of gases (measured at standard conditions) pass through per hour. The composition of these gases is not given, but from the specific gravity we might conclude that they contain on an average 10 per cent of carbon dioxide, since if they contained the maximum amount of that gas (about 20 per cent) their specific gravity would be 1.06 (air = 1). Assuming them, therefore, to contain

CO^2	10 per cent.
H^2O	10 "
CO, N^2, O^2.....................	80 "

their heat capacity per degree per cubic foot would be, between 350° and 1200°.

		Oz. Cal.
CO^2	$0.1 \times [0.37 + 0.00022\ (350 + 1200)]$	= 0.0711
H^2O	$0.1 \times [0.34 + 0.00015\ (350 + 1200)]$	= 0.0573
CO, N^2, O^2	$0.9 \times [0.303 + 0.000027\ (350 + 1200)]$	= 0.0310
	Sum	= 0.1594

Heat given up per cubic foot,

$$0.1594 \times (1200 - 350) = 125.5 \text{ oz. cal.}$$

Heat given up by gases per hour to boiler,

$$92{,}880 \times 125.5 = 11{,}656{,}500 \text{ oz. cal.} = 728{,}500 \text{ lb. cal.}$$

Heat in the steam produced per hour,

$$728{,}500 \times 0.45 \text{ (efficiency)} = 327{,}800 \text{ lb. cal.}$$

Heat equivalent of mechanical energy of steam engine per hour,

$$327{,}800 \times 0.20 \text{ (efficiency)} = 65{,}560 \text{ lb. cal.}$$

Heat equivalent of 1 hp-hour = 635 kg. cal. = 1,400 lb. cal

Horse-power generated by the engine,

$$65{,}560 \div 1{,}400 = \mathbf{46.8} \text{ H. P.} \qquad (11)$$

(12) Net available power after supplying fan,

$$46.8 - 0.5 = \mathbf{46.3} \text{ H. P.} \qquad (12)$$